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Multi objective Optimization of Friction and Wear of Pure and Glass Fiber Reinforced (GFR) Nylon 6 Composites using Taguchi based Grey Relational Technique

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Abstract—*Friction and wear are the main drawbacks found by industries which lead to replacement of parts. In this experimental work, investigate coefficient of friction and specific wear rate of pure and GFR Nylon 6 composites against 30 wt% GFR nylon 6 disc. Pin and disc specimens were injection molded and tested for friction and wear against 30 wt% GFR nylon 6 disc. Experiment was conducting based on* L_{16} *orthogonal array with three factors at four levels. The tribological test was carried out under dry conditions using a pin-on-disc machine at room temperature (*23^0C*), under varying glass fiber contents (0, 10, 20 and 30 wt %), different loads (5, 10, 15 and 20 N), sliding velocity (0.5, 1.0, 1.5 and 2.0 m/s) and constant sliding distance (1000m). Multi response optimization problem is converted into single response optimization problem using grey relational technique. Analysis of variance (ANOVA) was employed to find out the significance of factors (glass fiber content, applied load and sliding velocity) influencing coefficient of friction and specific wear rate. Confirmation test was carried out to validation the optimization results. Optical microscopy was performed to further understand the wear mechanism of worn surface of the pin specimen.*

Keywords*: Pure and GFR Nylon 6; mechanical property; Tribological property; Grey relational analysis*

1. INTRODUCTION

Friction, wear, fatigue and corrosion are the major drawbacks found by industries which lead to replacement of parts. Polymer have replaced by metals due to their superior properties such as excellent strength and stiffness to weight ratio, chemical resistance, corrosion resistance, impact resistance, fatigue resistance, thermal resistance, and low processing cost so polymer/polymer combination selected. However, there has been little information available on the tribological properties of polymer/polymer combinations, because polymers have low thermal conductivity and limited applied load and sliding velocity [1]. Polymer showed low friction coefficient compared to metals because of their low interfacial adhesion energy [2]. Nylon has excellent wear resistance, intrinsic lubrication behavior, tensile and flexural strength owing to carried out van der waal forces and hydrogen bonds in molecular chains of nylon thus used in gears, bearings and sliding machining elements [3]. The usage of polymer in food and chemical industries are essential as it avoids the usage of lubrication [4, 5].

Polymers have low wear resistance, mechanical strength, low thermal conductivity so several reinforcements and filler materials mixed to the polymer to upgrade their tribological, mechanical and thermal behaviour [6]. If applied load increases coefficient of friction decreases but only limited at elastic constant, when plastic deformation starts then coefficient of friction slightly increases due to further increases load [7]. When speed increases in case of PA/POM then coefficient of friction increases due to less thermal conductivity comparison with plastic/steel combination [8].

The objective of this paper is to study the friction and wear behavior of pure and GFR Nylon-6 pin against 30 wt% GFR Nylon-6 disc. In this study specific wear rate and coefficient of friction is measure with varying glass fiber content, loads and sliding velocities. The wear mechanisms of pin specimen were also studied.

Table 1: Mechanical properties of pure and GFR nylon 6 composites

Sl. No.	Glass fiber content (Wt %)	Shore hardness (D)	Notched impact strength (J/mm)	Ultimate tensile strength (N/mm2)	% Elongation	Density (g/mm3)
1	0%	63-65	0.1375	51.208	49.41	0.00113
2	10%	63-67	0.075	53.631	38.22	0.00120
3	20%	73-75	0.125	71.358	19.74	0.00127
4	30%	72-75	0.125	86.014	13.68	0.00137

2. EXPERIMENTAL SETUP

2.1 Specimens details

The polymer materials used in this study were pure and GFR nylon 6 present in form of granules. Mechanical properties of pure and various glass fiber contents shown in table [1]. Pin specimens were made by (0, 10, 20 and 30 wt %) GFR nylon 6 and disc specimens were made by 30 wt % GFR nylon 6 fabricated for friction and wear test using injection molding machine (Modern plastic and equipment's, Model-MPE-TLH-01). Temperature of injection molding machine maintained at 240°C. Pin specimen (31*5*5 mm) sliding against 30 wt % GFR nylon 6 rotating disc (70 mm diameter and 5 mm thickness) at a given sliding velocity.

2.2 Friction and wear testing

Tribological test were carried out under dry sliding condition as per ASTM G-99-05 standard on DUCOM TR-20M-106 pin-on-disc tribo tester with pure and GFR nylon 6 pin specimens sliding against 30 wt% GFR nylon 6 disc specimens. The disc which was used have surface roughness (Ra=0.6±0.05 µm) achieved by polished using several emery papers. Track diameter of pin specimen on disc was 40 mm. Friction and wear tests were done at various glass fiber contents (0, 10, 20 and 30 wt %) , applied loads (5, 10, 15 and 20 N), sliding velocity (0.5, 1.0, 1.5 and 2.0 m/s), constant sliding distance (1000 m) under dry condition at input temperature (23^0C) and humidity (67 ±10 %). Pin specimens were pre-worn using a 600 grade SiC emery paper for full contact between pin and disc surface. Pin and disc specimen was cleaned using acetone and thoroughly dried. The initial weight before experiment and final weight after experiment of specimen were weighted using an electronic digital analytical balance having an accuracy of 0.0001 g.

The specific wear rate K_S (mm^3/Nm) was quantified from the following equations:

$$\textit{Specific wear rate } (K_S) = \frac{m_1 - m_2}{\rho \times N \times S} \qquad (1)$$

Where m_1 and m_2 are mass of the pin specimen before and after experiment (g), ρ represents density of the pin specimen (g/mm^3), N represents applied load (N), and S represents sliding distance (m).

2.3 Design of experiment

Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with a small number of experiments only. The taguchi design of experiment approach eliminates the need for repeated experiments and thus reduced time, materials and costs. Taguchi analysis is a more powerful tool for the design of high quality system. In the present study parameter influencing coefficient of friction and specific wear rate such as varying glass fiber contents applied load and sliding velocity were considered as factors influencing process. In this experimental work design L_{16} orthogonal arrays was used where three factors and each of their four levels were investigated. Response variables are the output of experimental setup.

Table 2: Control factors and their levels

	Control factors	Levels			
		1	**2**	**3**	**4**
A	Glass fiber (wt %)	0	10	20	30
B	Applied load (N)	5	10	15	20
C	Sliding velocity (m/s)	0.5	1.0	1.5	2.0

2.4 Grey relational analysis

The grey system theory is useful in solving problems with insufficient, poor and uncertain information. Multi response optimization problem is converted into single response optimization problem using grey relational technique. The first step in grey relation analysis is to normalize the experimental data in the range between 0 and 1. This process is called grey relational generation. The normalized value of coefficient of friction and specific wear rate values corresponding to smaller the better equality criterion which can be expressed in this work. Therefore, the normalized S/N ratio x_{ij} for the íth performance characteristic in the jth experiments can be expressed in the following formula:

$$x_{ij} = \frac{\max_j \eta_{ij} - \eta_{ij}}{\max_j \eta_{ij} - \min_j \eta_{ij}} \qquad (2)$$

Where x_{ij} is the sequence after data processing, η_{ij} the original sequence of S/N ratio (where i=1, 2, 3…m, j= 1, 2, 3…n), max η_{ij} the largest value of η_{ij}, and min η_{ij} the smallest value of η_{ij}.

Basically, the larger normalized S/N ratio corresponds to the better performance and the best normalized S/N ratio is equal to unity. The grey relational coefficient is calculated to express the relationship between the ideal (best) and actual normalized S/N ratio. The grey relational coefficient ξ_{ij} for the íth performance characteristic in the jth experiment can be expressed as follows:

$$\xi_{ij} = \min_i \min_j \left|x_i^0 - x_{ij}\right| - \zeta \max_i \max_j \left|x_i^0 - x_{ij}\right| \qquad (3)$$

$$\left|x_i^0 - x_{ij}\right| + \zeta \max_i \max_j \left|x_i^0 - x_{ij}\right|$$

Where x_i^0 is the ideal normalized S/N ratio for the íth performance characteristic and ζ the distinguishing coefficient which is in the range $0 \leq \zeta \leq 1$.

After averaging the grey relational coefficients, the grey relational grade γ_i can be obtained, that is:

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} \xi_i (k) \qquad (4)$$

Where *n* is the number of process responses.

A higher value of the grey relational grade represents a stronger relational degree between the reference sequence $x_0(k)$ and the given sequence $x_i(k)$. A higher value of the grey relational grade means that the corresponding process parameter is closer to the optimal one.

2.5 Analysis of variance (ANOVA)

ANOVA is a statistical technique used to predict the significance of process parameters on the quality characteristics. This is done by separating of the total variability of grey relational grades, which is measured by the sum of squared deviation from the total mean of grey relational grade, contribution for each process parameter, error and F-ratio. The percentage calculations are deviation from the total mean of grey relational grade. Using Minitab 16 software, ANOVA is performed to determine parameter which has significant effect on the performance.

3. RESULTS AND DISCUSSION

3.1 Grey relational analysis of coefficient of friction and specific wear rate

The dry sliding wear testing experiments are conducted based on L_{16} orthogonal arrays and the experimental result for coefficient of friction and specific wear rate are shown in table [3]. Since there are two responses coefficient of friction and specific wear rate so this is multi response optimization problem. Multi response optimization problem is converted into single response optimization problem using grey relational technique. The first step in grey relational technique is to normalize the experimental data in range between 0 and 1. It is done to avoid the problems of difference in units and scale. The normalized values are shown in table [3]. The normalization of results is calculated according to lower the better criterion.

$$S/N = -10 \log \left[\frac{1}{n} \sum_{i=1}^{n} y_i^2 \right] \qquad (5)$$

The normalized values of coefficient of friction and specific wear rate are shown in table [3]. Ideally, the larger normalized value in both the responses is the best normalized value and are equal to unity. Further grey relational coefficient is calculated from the normalized value. In this study, equal weight age is given to the response so the distinguishing coefficient ζ is taken as 0.5. Grey relational grade is obtained by average of grey relational coefficients. By using grey relational grade multi response characteristics converted in single response [9]. Highest grey relational grade show optimum level of factor. Using Minitab 16 software, the grey relational grade are converted into S/N ratio according to larger the better criterion shown in fig [1]. The effect of each factor with level shown in table [4].

The highest average grey relational grade for each factor will be optimum parameter. It is shown from the fig. [1] That the optimum designs parameter combination for minimum coefficient of friction and specific wear rate.

3.2 Analysis of variance (ANOVA)

ANOVA analysis was done for Grey relational grades and the results are presented in Table [**5**]. The F values indicate that the change in a design variable has a remarkable effect on the tribological test. The glass fiber content has the most contribution on the output followed by sliding velocity and applied load. It is observed that the glass fiber has the highest contribution on friction and wear thus the most significant parameter.

3.3 Confirmation tests

Once the optimal level of the design parameters has been determined, the final step is to predict and verify the improvement of the quality characteristic using the optimal level of the design parameters. The predicted value of grey relational grade is 0.705061 which is in good agreement with the experimental value 0.692395 (A1B4C4).

Table 3: Grey relational analysis

Exp Run	GFR (Wt %)	Load (N)	Sliding Velocity (m/s)	Coefficient of Friction (μ)	Specific Wear Rate (mm3/Nm)	Normalized values (COF)	Normalized values (SWR)	Grey coefficient (COF)	Grey coefficient (SWR)	Grey grade	Orders
1	0	5	0.5	0.374	0.0000884	1	0.145718	1	0.369199	0.6846	2
2	0	10	1.0	0.260	0.0001680	0.531936	0.294829	0.516495	0.414879	0.465687	9
3	0	15	1.5	0.190	0.0011600	0.128134	0.743541	0.364467	0.660975	0.512721	5
4	0	20	2.0	0.201	0.0035000	0.20059	1	0.38479	1	0.692395	1
5	10	5	1.0	0.281	0.0001000	0.631932	0.174351	0.575992	0.377174	0.476583	7
6	10	10	0.5	0.292	0.0000500	0.681367	0.013383	0.610774	0.336334	0.473554	8
7	10	15	2.0	0.194	0.0030000	0.154956	0.964202	0.371735	0.933187	0.652461	3
8	10	20	1.5	0.185	0.0021000	0.093801	0.881372	0.355569	0.808241	0.581905	4
9	20	5	1.5	0.201	0.0001250	0.20059	0.226171	0.38479	0.392517	0.388654	15
10	20	10	2.0	0.193	0.0008890	0.148303	0.681751	0.369905	0.611061	0.490483	6
11	20	15	0.5	0.210	0.0000472	0.256981	0	0.402247	0.333333	0.36779	16
12	20	20	1.0	0.179	0.0005200	0.051356	0.557214	0.34515	0.530343	0.437747	10
13	30	5	2.0	0.210	0.0002220	0.256981	0.359554	0.402247	0.438425	0.420336	12

14	30	10	1.5	0.186	0.0002000	0.100742	0.335319	0.357332	0.429302	0.393317	13
15	30	15	1.0	0.198	0.0001380	0.18123	0.249147	0.379141	0.399727	0.389434	14
16	30	20	0.5	0.172	0.0004440	0	0.520522	0.333333	0.510476	0.421905	11

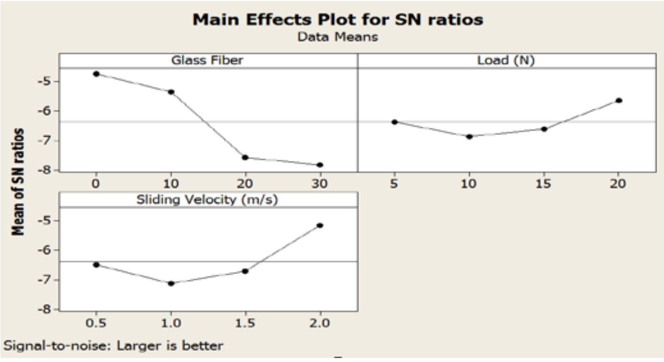

Fig. 1: Effect of control factors with their levels

Table 4. Response table of S/N ratio (Grey relational grade)

Levels	Glass fiber (A)	Applied load (B)	Sliding velocity (C)
1	-4.731	-6.366	-6.492
2	-5.335	-6.856	-7.111
3	-7.565	-6.598	-6.705
4	-7.830	-5.642	-5.154
Delta	3.099	1.214	1.956
Rank	1	3	2

Table 5: Analysis of variance of grey relational grade

Source	DF	Seq SS	Adj MS	F	P	% contribution
Glass fiber	3	0.098689	0.032896	7.03	0.022	57.33
Load (N)	3	0.012628	0.004209	0.90	0.494	7.33
Sliding velocity (m/s)	3	0.032703	0.010901	2.33	0.174	19.00
Residual Error	6	0.028093	0.004682			16.32
Total	15	0.172113				100

3.4 Worn surface morphology and effect of factors

Optical microscopy of the worn surfaces of pure nylon 6 at 2.0 m/s sliding velocity and 20 N applied load shown in fig. [2a]. In this case show plastic deformation means melt of pin specimen. The reason of this is temperature rise in contact zone because less thermal conductivity so pin specimen softening. Fig. [2b, c, d] shows the worn surface of nylon 6 under varying glass fiber content there observed shiny spot surface which represents the rubbed glass fiber. This is main cause to decrease specific wear rate. During sliding applied load shared by both glass fiber and nylon, but major part of applied load shared by glass fiber so if glass fiber content increases then coefficient of friction decreases. In case of glass fiber content due to rubbing of glass fiber of faced materials coefficient of friction decreased. Another main cause for variation in coefficient of friction is due to temperature of contact zone. The coefficient of friction decreases with the load increasing. If sliding velocity increased coefficient of friction decreases due to change in temperature of surface of specimen and contact zone. When glass fiber content increases hardness and thermal conductivity increases hence specific wear rate decreases. In case of pure nylon 6, specific wear rate more observed and when glass fiber content increases specific wear rate decreased so in the case of GFR nylon 6, specific wear rate decreased. If applied load increases specific wear rate increases due to increasing area of contact between pin and disc specimen, which produced more heated at contact zone and viscous-elastic property so specific wear rate increases. When sliding velocity increases the specific wear rate also increases due to increases in contact zone of pin specimen.

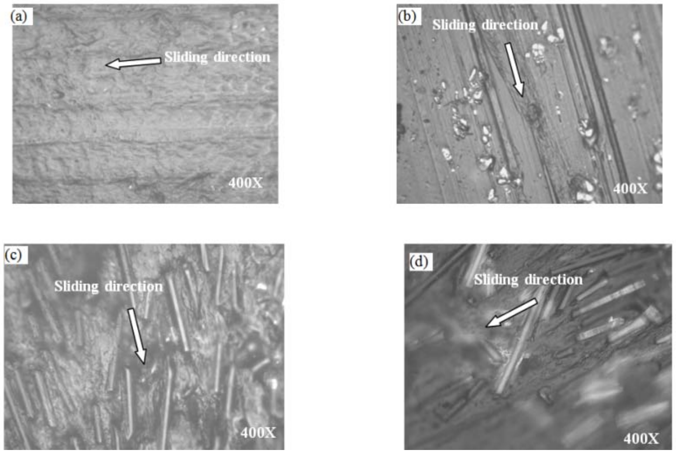

Fig. 2: Morphology of worn surfaces of the nylon 6 composites under varying glass fiber content and velocity at a load of 20 N :(a) 0 wt% GF, 2.0 m/s (b) 10 wt% GF, 1.5 m/s (c) 20 wt% GF, 1.0 m/s (d) 30 wt% GF, 0.5 m/s

4. CONCLUSIONS

In this experimental investigation, grey relational technique was used to optimize process parameter. On the basis of study, the following major conclusions can be drawn.

- On the basis of taguchi analysis of grey relational grade observed that A1B4C4 combination gives minimum coefficient of friction and specific wear rate. The optimum combination of test parameters are 0 wt% glass fiber content, 20 N applied load and 2.0 m/s sliding velocity.
- On the basis of ANOVA of grey relational grade observed that glass fiber content 57.33 %, sliding velocity 19 % and

applied load 7.33 % exerts a significant influence on multiple response.

- The worn surface of pure nylon 6 specimen shows plastic deformation means melt of polymer while GFR nylon 6 shows sliding direction with breakage of glass fiber.

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